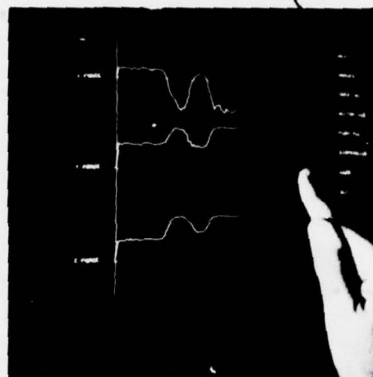
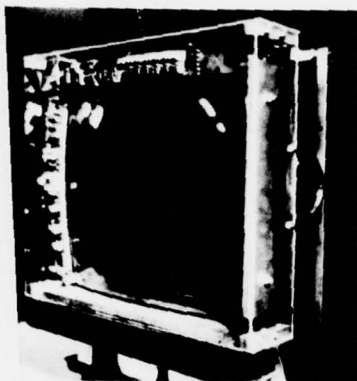


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One-Point Touch Input of Vector Information for Computer Displays

Nicholas Negroponte
Christopher Herot
Guy Weinzapfel

October 1978

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↙ 20. open a rich channel for immediate and multi-dimensional interaction.

The project is an example of basic research with potential for future application. The report will be of interest primarily to research scientists in the field of graphic CRT displays. ↙

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The Human Factors Technical Area of the Army Research Institute is concerned with demands of the increasingly complex future battlefield for improved man-machine systems to acquire, transmit, process, disseminate, and utilize information. The research is focussed on the interface problems and interactions within command and control centers and is concerned with such areas as topographic products and procedures, tactical symbology, information management, user oriented systems, staff operations and procedures, and sensor systems integration and utilization.

One area of special research interest is the design of effective and efficient on-line interaction between the operator/user and the computer. Research is focused on enhancing computer-based query languages and associated features of tactical data input, retrieval and analysis. The present publication explored interactive graphic techniques employing a touch/pressure sensitive panel placed over a display. The panel allows even a computer-naive person to use fingers for manipulating displayed information. The effort is part of the exploration of improved ways for the user and computer to communicate and provides a necessary technological base for effective design of the interface.

Research in the area of concepts for man-computer synergism is conducted as an in-house effort augmented by contracts with organizations selected for their specialized capabilities and facilities. The efforts are responsive to general requirements of Army Project 2Q162722A765 and to special requirements of the U.S. Army Combined Arms Combat Development Activity, Ft. Leavenworth, KS. This specific effort was conducted under Army Project 2Q161102B74F as basic research responding to the above requirements.

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1.0 INTRODUCTION.

Recently, interest has grown around a class of instruments known as touch-sensitive digitizers (TSD's). Using a variety of technologies¹, these devices are capable of determining the X, Y position of a finger's touch without resorting to an intermediate physical stylus.

The excitement generated by TSD's derives directly from their ability to provide a more natural input path to the computer. The umbilical cord attached to the conventional stylus is removed; in fact the entire notion of a physical stylus is voided. Also, dislocations caused by separate input and presentation surfaces can be circumvented by superimposing transparent TSD's directly over display surfaces.

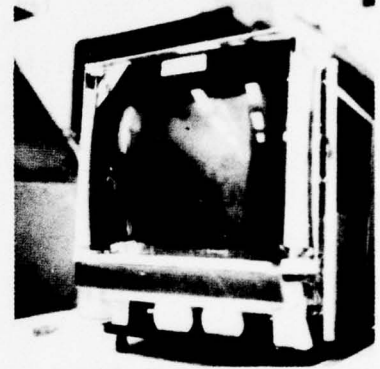


While the potentials for more natural, coincident and even multi-finger input are obvious and are being developed by other programs, little exploration has been undertaken in the area of multi-dimensional input - the sensing of pressure as well as location parameters. Yet this domain offers a rich potential for man-machine interaction. The work described in the following pages was designed to explore that potential -

to test the ability of the human stylus to moderate pressure and direction inputs from a single touch.

1.1 OUR LABORATORY'S TSD.

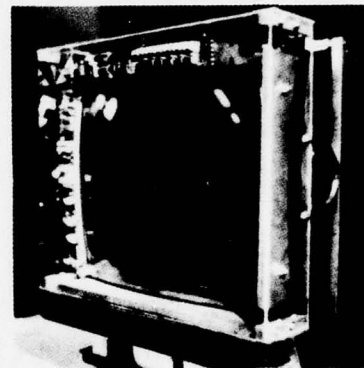
In April, 1976, the Architecture Machine Group acquired a TSD from Instronics, Ltd. of Ontario, Canada. This device consists of a sheet of clear glass with piezoelectric transducers mounted on two adjacent edges. The glass is doubly curved to match the face of a display tube. The transducers are used to induce acoustic waves in the surface of the glass. These waves are reflected back to their source by fingers touched to the glass surface. The location of the touch is determined by ranging those echos.



It was hoped that the TSD would enable users to sweep their fingers over the display surface thus drawing, even "fingerpainting" with the computer. It was found, however, that in order to insure proper input readings, users had to press the TSD with a force that generated friction between finger and glass sufficient to prevent smooth, sweeping gestures. As a result, the device seemed better suited to pointing than to drawing or painting.

This reality, however, opened the possibility of using the finger-glass friction to unique advantage. Namely, the TSD could be mounted on the display with strain gauges such that forces induced by the finger could be used to specify pressures both normal to and parallel with the input surface. In this way, the device could become a pressure (as well as touch) sensitive digitizer - a TSD/PSD.

Such a configuration was implemented (as described in Section 3.0) and provided the basis for a four month research program designed to evaluate the characteristics of pressure sensitive input. The following section discusses the methods used to conduct that evaluation.



2.0 APPLICATIONS.

Five input routines were developed to assess the input characteristics of the PSD. These included:

1. Force Cursor,
2. Vector History,
3. Pushing/Pulling,
4. Dispersion, and
5. Rotation

In addition, an attempt was made to utilize the X and Y torques to determine the position of the finger,

so as to eliminate the need for a TSD altogether.

2.1 FORCE CURSOR.

The initial routine provides the pressure sensing equivalent of a conventional cursor. It does this by displaying a vector, or arrow, whose origin coincides with the touch point, whose head lies in the direction of the force being exerted by the finger, and whose length is proportional to that force. At the same time, the z force (pressure normal to the face of the screen) is reported as a square, whose size is proportional to that force.

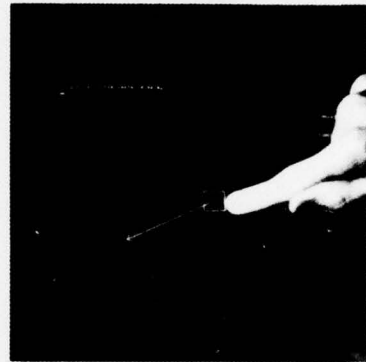


Use of the force cursor has produced some surprising results. While its function is obvious to all who observe it, many people experience initial difficulty making it behave as they expect. Most notably, novice users have difficulty making the vector point in the directions they desire. This difficulty derives not from the equipment, but from the fact that people do not always press in the directions which their fingers appear to indicate. Typically, this problem is encountered with the user's first vector. The novice will press the tablet causing an



arrow to appear in proper alignment with the finger; but as the finger is rotated, the direction of the vector often fails to follow. Close observation has revealed that this results from the fact that the user actually maintains pressure in the original direction though the finger changes orientation.

Fortunately, the learning curve with this routine is quite steep. Following initial difficulty, most users are able to control the direction of their vectors with less than a minute's practice. In fact, many users, realizing that the orientation of their fingers is irrelevant to the direction of the vector, are able to manipulate the cursor from a single, natural hand position.



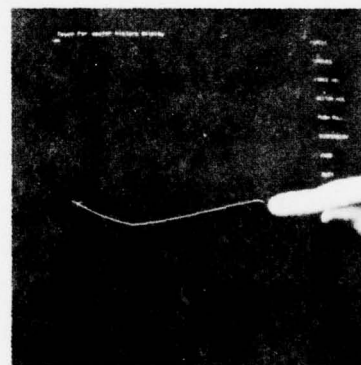
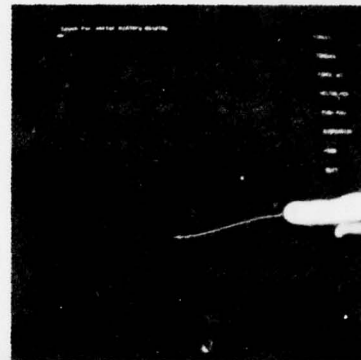
Beyond this initial training problem, there is a more chronic difficulty; placing the tip of the arrow with acceptable accuracy. This is especially true as greater extensions (and hence larger forces) are attempted. This problem is similar to that of using a long pointer at a blackboard; the vector bobs and wobbles at its greatest extension. In an attempt to counteract this drawback, a damping effect was added to the cursor routine to

filter out minor pressure fluctuations. However, users continue to find the device a difficult mechanism with which to point accurately. This may be due to the relationship between force input and vector length, which was arbitrarily chosen to be linear. Had a logarithmic relationship been used, the problem of accuracy may have been alleviated. This possibility was not pursued, however, due to the time pressures of the project. Nonetheless, the force cursor demonstrates that the PSD can be used for general statements of direction and magnitude.

2.2 VECTOR HISTORY.

The second routine was designed to evaluate the potential for guiding a cursor from a stationary input position. In this case, the cursor scribed a path as it moved under control of the finger's pressure. This routine underwent two implementations. In the first, the speed of the cursor was constant; only its direction was controlled through the PSD. A later implementation allowed the speed to be controlled as well.

Most users, having trained with the force vector encountered little difficulty in directing the mobile cursor.



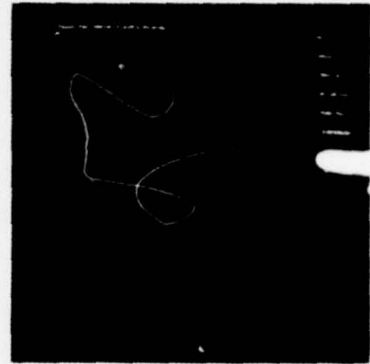
For example, many people were able to write their names on their first attempt.

Surprisingly, though, the variable speed version was more difficult to use. This results from the fact that the cursor deviates from an intended path, most people's reaction is to press harder on the input surface. Since this does not necessarily change the cursor's direction but does increase its speed, "errors" are exaggerated.

Nonetheless, the process of controlling a mobile cursor from a single point on the screen appears to be an engaging and successful use of the device. Real world applications (such as navigating about a map display) can easily be imagined for its use.

2.3 PUSHING/PULLING.

To explore the PSD's potential for moving objects other than a cursor, a routine was implemented which allows users to move squares about the screen. Here, the user points to an object and gives it a push. The touch is used to identify the object, the pressure to impart a direction and speed. Thereafter, the user does not need to track the



figure, but can direct its movements remotely.

Use of this routine demonstrated it to be a obvious and comfortable means for directing the movement of selected objects. Unfortunately, time constraints prevented an elaboration of this algorithm to incorporate parameters for objects of differential weight and/or coefficients of friction. As a result, there is no means of knowing if a user could gain a sense of an object's "physical" attributes by using the PSD. However, experience with the simple implemented routine suggests such feedback is within the capabilities of the device.

2.4 DISPERSION.

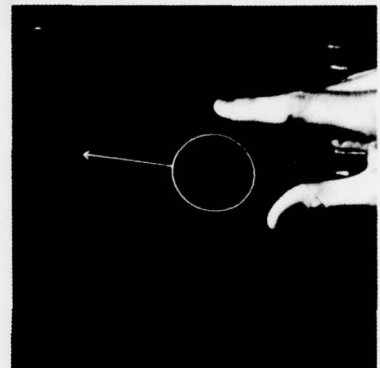
In perhaps the most engaging of all the PSD applications, graphic shooting gallery was devised to test the system's ability to accomodate dispersing inputs. This routine causes small, bb-like circles to emanate from the user's finger tip as it is pressed on the screen's surface. Since the number, speed and direction of the bb's can be controlled by the finger, a procession of moving targets (in fact, small ducks) is played across the top of the screen to test the accuracy and flexibility of those inputs.



Interestingly enough, even users who had experienced some difficulties with the previous routines, adapted to the requirements of this application quite rapidly. In fact, some "hunters" advanced to the point where selected ducks could be felled with single shots. This represents remarkable control, indeed.

2.5 ROTATION.

The final routine was designed to evaluate the PSD's ability to measure torque inputs and to use those measurements to advantage in interaction. For this purpose, a simple knob is displayed on the screen with an arrow indicating its angular position. It was hoped that torque about the z axis could be measured with sufficient sensitivity that even minute twists of a single finger could be used to turn the displayed knob. However, when tuned to a level sensitive enough to measure these subtle inputs, the user's intentions were overshadowed by vibrations in the room and in the equipment itself. Fortunately, after lowering the sensitivity of the z torque pickup, it is now possible for users to turn the knob with two fingers. In fact, the position of the knob can be adjusted to within 5 degrees of rotation with



little difficulty. Further tuning of the algorithm and the hardware would permit even greater accuracy. Though a single, rather sizeable knob was used for this application, the success achieved opens numerous additional possibilities. For example, specific machine parts in a complete display could be identified and reoriented via simple, direct manipulation, this obviating the need for multiple (object selecting and action specifying) commands.



2.6 POSITION DETECTION.

In addition to the five capabilities described above, it was hoped that a means of detecting the position of a surface touch could be accomplished directly by the PSD without using the echo ranging of the Instronics device. The algorithm used for this measurement divided the X and Y torques by the Z force. The results of this function were normalized for the direction of forces parallel to the input surface and amplified to produce the location of the finger. While the results of this approach were consistent, their accuracy was too poor to be of use; the points reported would oscillate about an area nearly one tenth the size of the screen.

The source of this inaccuracy was ultimately ascribed to the configuration of the strain guage mounting. Namely, the sensitivity of the torque pickups was so great that room vibrations generated a 10 percent noise factor in the measurements. While this noise was not problematical in the other routines, the error induced in position detected greatly exceeded acceptable levels. It was concluded that a different mounting configuration might overcome this drawback. This is discussed in Section 3.0, description of the hardware.

2.7 EXTENSIBILITY.

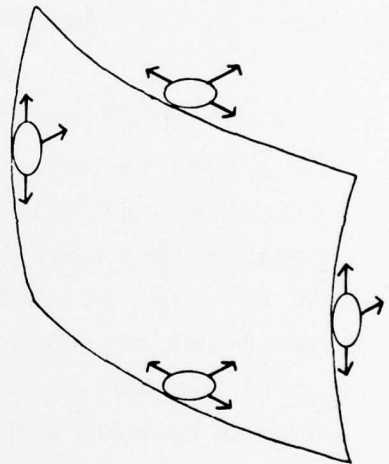
It should be noted that these five applications described above were selected because they were each imminently doable in the time available. It was clear from the onset how each capability should work; and the amount of programming required by each was quite limited. In short, the five routines were appropriately matched to the scale of the four month duration of the research.

It is not difficult, however, to imagine more elaborate uses for a pressure sensitive device. For example, a three dimensional dynamic modeling system could use the PSD for tactile manipulation of machine parts, building

envelopes, and the like. It is easy to imagine turning a machine part by twisting its representation on the screen, or rotating the display of a building by pushing on the edge of a facade. In short, the potentials for tactile involvement and physical feedback from such a device were only hinted at by this brief exploratory work.

3.0 PRINCIPLES OF OPERATION.

The PSD employs eight strain gauges two each secured to mounting rings centered on the four sides of the TSD. Of the two gauges secured to each ring, one measures force perpendicular to the glass and the other measures shear parallel to the glass. These eight measurements are then used to derive the three force and three torque outputs which are used by the routines described in the previous section.

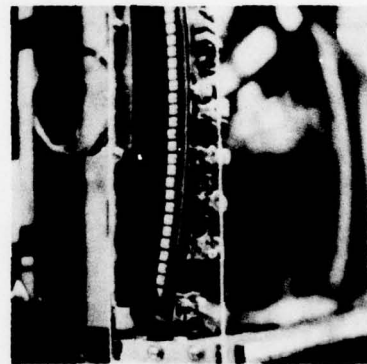
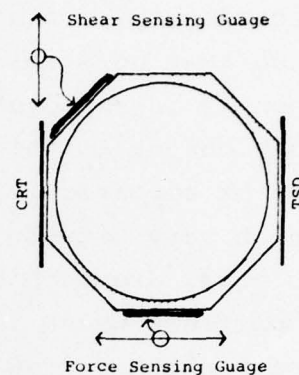


3.1 MOUNTING AND STRAIN GAUGES.

The TSD is secured to the CRT by means of four, specially machined, octagonal, aluminum rings. All forces exerted on the TSD transmitted to these rings, thus causing deformations which in turn flex the strain gauges secured to them. The

two gauges are cemented to each ring as shown in the adjacent figure. Their placement insures that the forces which they sense are orthogonal to one another.

It happens that the thickness, and hence flexibility of these rings is critical to the sensitivity of the gauge's measurements. Unfortunately, the rings machined for this implementation were designed to accomodate very subtle pressures; the fact that the TSD necessitates high finger pressures was not taken into account in their design. Nor was the vibration from nearby machinery foreseen as a problem. As a result, development of the five input routines was somewhat hampered by vibration and pressures which exceeded the output range of the gauges and related circuitry. Were the equipment to be rebuilt, heavier rings would greatly improve its performance. Alternatively, load cells, rather than strain gauges might be used. Load cells measure pressure without deformation. However, these devices are significantly more expensive than the strain gauges used for this implementation.



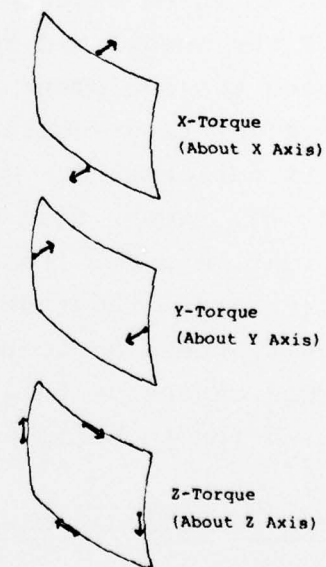
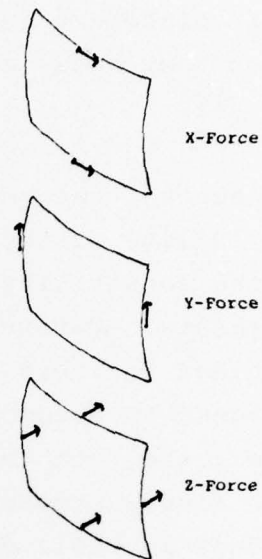
3.2 ELECTRICAL DESCRIPTION.

The PSD utilized nine BLH (SPB3-35-500)

semiconductor strain gauges. Semiconductor gauges were selected because of their sensitivity to miniscule strains. However, as semiconductor devices, they are also very sensitive to changes in temperature. Accordingly, a ninth gauge mounted such that no strain could be exerted upon it is employed to provide a reference output to which all other gauges can be compared. The gauge outputs, which vary between 10 millivolts peak to peak, are each connected to preamplifiers which import a gain of 50, the resultant "raw" output is .5 volts peak to peak.

The "raw" voltages from the strain gauge preamplifiers are combined by sum and difference networks to produce outputs which correspond to X force, Y force, Z force, X moment, Y moment, and Z moment. The sums of opposite torque gauges are used to provide forces along each axis, while the differences are used to provide the torques about each axis.

The six force and torque outputs are converted to digital signals by a Burr-Brown SDM853 data acquisition system (DAS). The inputs to the DAS are limited to 6.2 volts to prevent



overloading the A/D converters. The DAS produces a 12 bit output for each of the 6 analogue inputs.

3.3 DIGITAL INTERFACE.

The outputs from the DAS are stored in a buffer, allowing the DAS to assemble the next sample while waiting for the computer to read the current values.

The computer interface allows program selection of either byte or halfword mode. In byte mode, only 8 most significant bits of each force and torque are used, allowing fast and easy access to the data. In halfword mode, the programming is a bit more complicated, but all of the data bits are available. Due to the influence of vibration on low order bits, the device was operated primarily in byte mode for the experiments described here.

3.4 SYSTEMS SOFTWARE.

The PSD is equipped to interrupt the computer when data is available. However, since the PSD is always used in conjunction with the TSD the interrupt circuitry of that device was used. When the TSD detect the finger touch, the program reads the position from the TSD and the forces and torques from

the PSD. Since hysteresis of the strain rings and uncompensated temperature drift often cause the untouched PSD to produce non-zero readings, it is additionally important that the TSD interrupt be used. When the software detects that the device is not being touched, it reads the values of the forces/torques so as to use them as offsets for inputs next time the PSD is touched.

Drift due to temperature changes generated problems for the initial input routines. This was overcome by adding software to sample the force and torque readings when the TSD was not being touched. The latest reading, then, were used as offsets for subsequent inputs. However, this software compensation was made at the expense of the system's overall response range: the offsets biased the device unpredictably. A zeroing circuit was designed to correct for temperature drift in hardware. This circuit was not installed due to the short duration of the study and the anticipated cost associated with its installation.

4.0 CONCLUSIONS.

As a laboratory experiment, the PSD demonstrated a potential for new and powerful interaction techniques. Perhaps

the most significant feature of the PSD is the immediacy and richness of the tactile man-machine interaction which it affords. In one positioning of the finger, the user can indicate location, direction, and magnitude. With such a physically engaging device environment, complex activities need not require a lengthy sequence of typed commands or menu selections. Clearly the PSD could be used in a command and control application to overlay a map, selecting symbols and setting them in motion. In the manner of the dial described in Section 3.2, actions could be performed on any of a large selection of graphical entities spread out over the entire display.

1 A discussion of various TSD technologies is provided in the report "Touch Sensitive Displays" by Dr. Richard A. Bolt, Architecture Machine Group, M.I.T. Cambridge, Massachusetts, September 1976.

2 A more complete technical description of the TSD is provided in reference cited in footnote 1.